Research on Countermeasures of Wind-induced Vehicle Overturning and Threshold-exceeding Wind Duration

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1. Introduction

To avoid the wind-induced road vehicle accident, countermeasures are desired. In this study, vehicle overturning probability as a safety index is calculated by considering the vehicle type. In addition, threshold-exceeding duration of wind and wind speed prediction is conducted for purpose of duration prediction of strong wind.

2. Safety assessment of overturning considering traffic

As the input vehicle weight and aerodynamic coefficients are determined randomly: for aerodynamic coefficients, factor of various vehicle types are firstly determined and factor of vehicles for a certain type is generated randomly according to uniform distribution, finally the aerodynamic coefficients are gained by multiplying the factors by the coefficients of a cuboid model, which simulates the overturned vehicle in Oomishima Bridge; the weight of vehicles is assumed to obey log-normal distribution. Based on the proportion of vehicles belonging to different type for the Kobe-Awaji-Naruto Expressway and the assumption of a traffic flow with 10,000 vehicles, the probability of overturning is calculated 100 times and averaged for each case.

Results are shown in Fig.1 and Fig.2. The former corresponds to workday in February with 37.03 % total proportion of medium, large and oversize vehicle while the latter corresponds to holidays in May with 6.81% total proportion. The overturning probability is higher in Fig.1, which indicates that the safety countermeasure is more desired for road sections with high total proportion of medium, large and oversize vehicle.

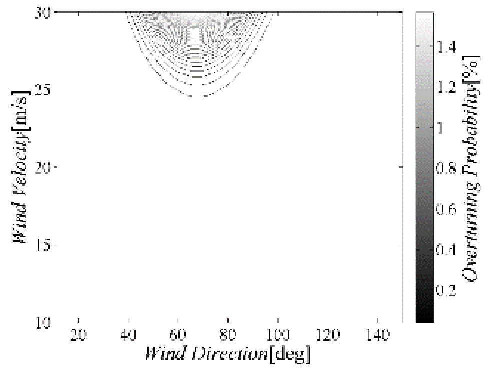

Fig.1 Workday in Feb.

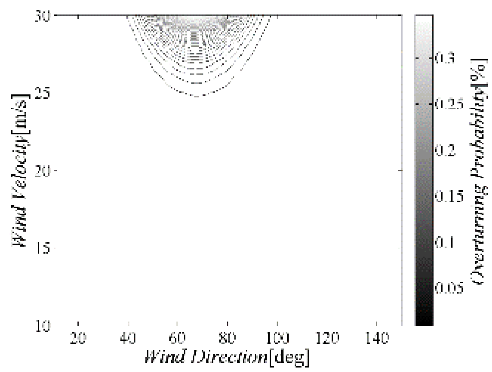

Fig.2 Holiday in May

3. Analysis on threshold-exceeding duration

Analysis on threshold-exceeding duration of wind is very necessary for the prediction of strong wind duration. The average duration of threshold wind speed exceedance is calculated by,

$$\bar{t}(a) = \frac{t_1(a)+t_2(a)+\cdots+t(a)}{j} \quad (1)$$

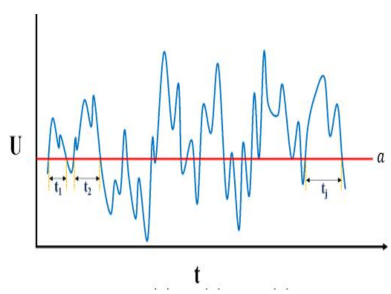

Fig. 3 The wind speed vs. time

Keywords: vehicle overturning probability, wind speed prediction, threshold-exceeding duration of wind
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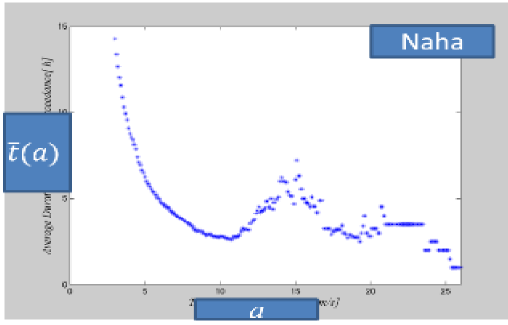

Fig. 4 $\bar{t}(a)$

In equation (2),a is threshold, t_i is threshold-exceeding duration, j is total number of threshold exceeding, $\bar{t}$ is average duration. Road administers can know how long on average a strong wind with speed larger than a continued in the history easily from Fig. 4.

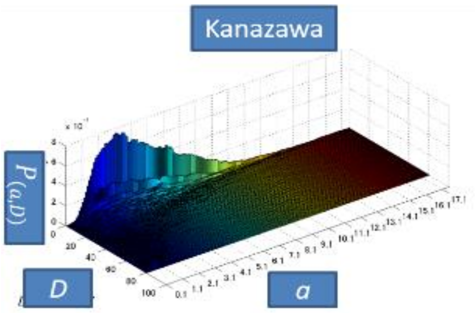

Fig. 5 $P_{(a,D)}$

Then, appearing probability distribution of the duration when threshold varies from the minimum wind speed to the maximum wind speed at interval of 0.1 m/s is analyzed. The distribution of probability is obtained by,

$$P_{(a,D)} = \frac{c_{(a,D)}}{\sum_{i=1}^{i=amax}\sum_{j=1}^{j=Dmax} c_{(i,j)}} \quad (2)$$

From the result in Fig. 5, administers of road could obtain the value of probability directly now. Based on this, prediction of duration will also become possible.

4. Wind speed prediction

Autoregressive Process (AR) model which is suitable for stationary process and Autoregressive integrated moving average Processes (ARIMA) model which is suitable for nonstationary process are firstly applied. AR model is represented as [1],

$$\tilde{z}_t = \phi_1\tilde{z}_{t-1} + \cdots + \phi_p\tilde{z}_{t-p} + a_t \quad (3)$$

where the symbols $\phi_1, \phi_2, \ldots, \phi_p$ is a finite set of autoregressive parameters of the time series $\tilde{z}_t$. ARIMA model is represented as,

$$\nabla^d\tilde{z}_t = \phi_1\nabla^d\tilde{z}_{t-1} + \cdots + \phi_p\nabla^d\tilde{z}_{t-p} + a_t - \theta_1 a_{t-1} - \cdots - \theta_q a_{t-q} \quad (4)$$

where ∇ is the differencing operator.

For Markov chain model, we assume the dynamic of the time series is full determined by the set of all transition probability $p(s_{k+1}|\, s_k,\ldots,s_{k-l+1})$. Delay vectors of dimension $m=l$ and unit time lag form the states onto which these transition probabilities are conditioned. Because of the smoothness of the transition probability, the future observations s_{k+1} of all delay vectors $\mathbf{s}_k \in \mathcal{U}_\varepsilon(\mathbf{s}_n)$ which are neighbors of $\mathbf{s}_n$ in state space are subject to the same transition probability and form a finite sample of $p(s_{n+1}|\mathbf{s}_n)$, Markov chain is written as[2],

$$\hat{s}_{n+1} = \int s' p(s'|\mathbf{s}_n) ds' = \frac{1}{\|\mathcal{U}_\varepsilon(s_n)\|}\sum_{k:s_k \in \mathcal{U}_\varepsilon(s_n)} s_{k+1} \quad (5)$$

The prediction accuracy is measured by mean absolute error (MAE), mean square error (MSE), and correlation coefficient (R). Results for predicting one-step ahead 10-min mean wind speed at HeronIsland are shown in Table 1, with 15793 training data and 5264 testing data.

Table 1 Prediction accuracy

	AR	ARIMA	Markov chain
MAE	1.742	1.204	1.344
MSE	2.683	2.204	2.227
R	0.911	0.980	0.976

6. Conclusion

For the road section with high proportion of medium, large and oversize vehicles in the traffic, safety countermeasure is more desired. $P_{(a,D)}$ is obtained by analyzing meteorological data, which will help road administers to provide more effective traffic regulation. ARIMA model has the best prediction accuracy for the data from HeronIsland.

Acknowledgement: We express our gratitude to Honshu-Shikoku Bridge Expressway Company Limited for providing us wind velocity data.

Reference:

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